

# Quark Flavor Physics:

## Possibilities

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P5

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# Flavor Physics = Particle Physics

The  $K$  meson has been at the heart of most of the advances in particle physics:

- Strangeness
- Mixing of neutral kaons
- $\tau - \theta$  puzzle leads to parity violation
- Strangeness leads to  $SU(3)$
- $SU(3)$  leads to quarks
- CP violation in  $K_L$  decay
- Absence of neutral weak currents leads to postulate of charm
- $\epsilon'/\epsilon$  shows direct CP violation

# FCNC and CP Violation

- Flavor Changing Neutral Currents suppressed:
  - $\mathcal{B}(K_L \rightarrow \mu^+ \mu^-) = 7 \times 10^{-9}$
  - Standard Model explanation
    - \* CKM matrix nearly diagonal
    - \* (Most) quark masses small compared to  $m_W$
  - Beyond SM must suppress FCNC too: enormous constraint
- The CP Enigma
  - Why is  $\theta_{QCD}$  small? why is the EDM of the neutron small?
  - Why is there something rather than nothing?
  - There is more to CP than CKM.

# Incompleteness of Standard Model

- Electroweak symmetry breaking not understood
- SM explains everything we see, but we don't see most of the stuff in the universe
- Extensions of SM must pass the CP and FCNC tests
- Look for non-SM effects
  - Radiative corrections at  $Z$
  - EDMs
  - Test unitarity triangle
    - \* Sides:  $b \rightarrow u \ell \nu$ ,  $x_s$ ,  $K \rightarrow \pi \nu \nu$  ...
    - \* Angles:  $B \rightarrow J/\psi K_S$ ,  $B \rightarrow \pi \pi$ , etc.

# History of Virtual Discoveries

- 1934: Enrico Fermi (or Ernest Rutherford in 1898) discovered the  $W$
- 1973: Gargamelle discovered the  $Z$
- 1974: Ben Lee and Mary K. Gaillard discovered charmed particles
- 1994: LEP discovered the  $t$  quark

**Predictions of real particles from virtual effects are astonishing.**

**But few are convincing until the real thing appears.**

# Context for Next Generation Quark Flavor Experiments

- LHC begins ca. 2007, results begin ca. 2008
- Possible scenarios at LHC
  - Discovery new spectroscopy: jackpot for particle physics
  - Discover single, orthodox Higgs boson: happy for 24 hours
  - Strongly interacting  $W$ ,  $Z$  (disfavored): life is tough
  - ???

# Quark Flavor Physics in LHC Era

- If there is a new spectroscopy:
  - Confirm predicted radiative corrections?
  - Discriminate between possible models?
- If there is an orthodox Higgs
  - Confirm Standard Model predictions
- Something else
  - Confirm (modified?) Standard Model predictions
- A higher standard:
  - With competition from LHC, it will not be enough to find hints of new physics. The demands on precision and clean interpretation will be much greater.

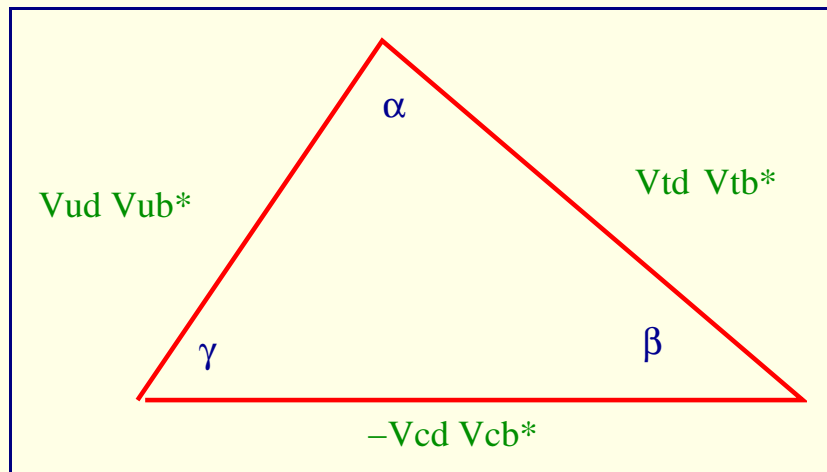
# Value of Verifying the Standard Model

- The Standard Model is great!
- LEP/SLC provided magnificent confirmation of part of SM (up to a point)
- Weak-decays are the means to confirm other parts
- This great theory warrants extensive validation
- Already testing loops (mixing,  $b \rightarrow s\gamma$ )

# CKM and All That

- CKM matrix provides weak phases (1st to 3rd transitions only)

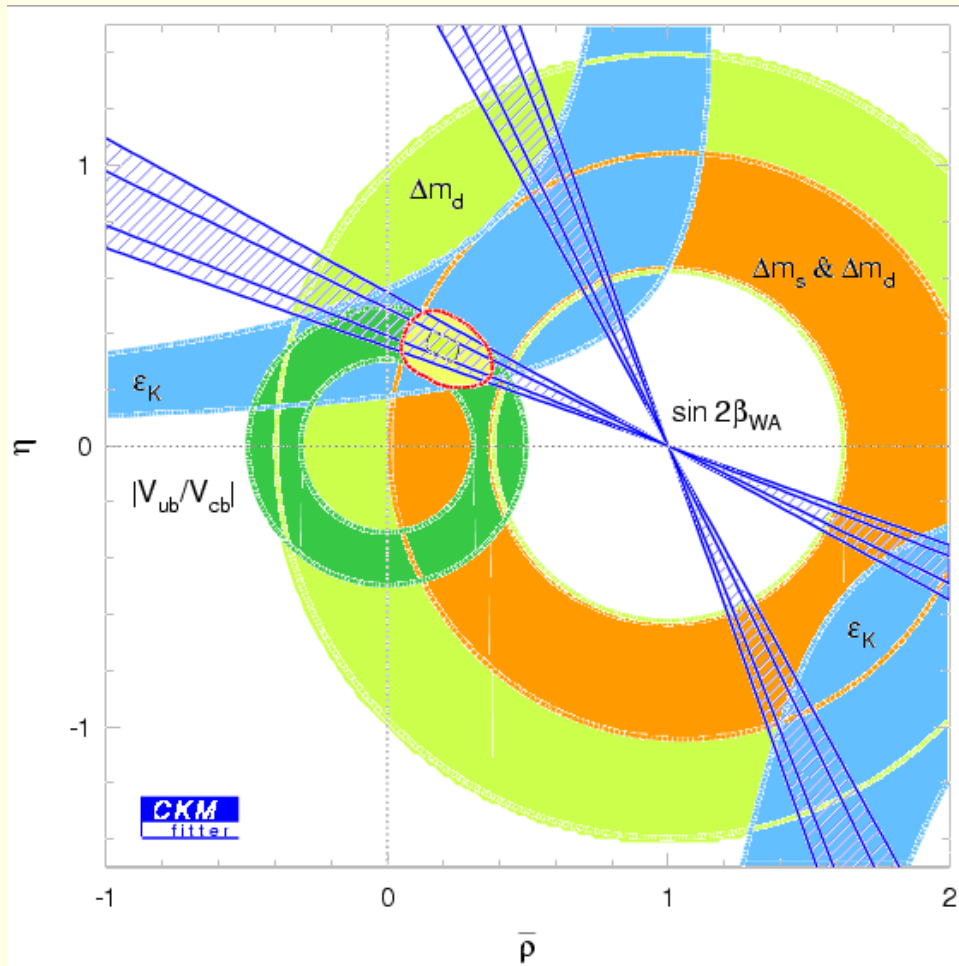
$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} = \begin{bmatrix} 1 - \lambda^2/2 & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & \lambda^2 A \\ \lambda^3 A(1 - \rho - i\eta) & -\lambda^2 A & 1 \end{bmatrix}$$



- Measure  $\sin 2\beta$  in  $B \rightarrow J/\psi K_S$ , etc.
- Measure  $\sin 2\alpha$  in  $B \rightarrow \pi\pi, \rho\pi$  etc.
- Measure  $\gamma$  in  $B \rightarrow DK$ , etc.
- Measure  $V_{ub}, V_{cb}$

Wolfenstein representation:  $V_{ub} \propto e^{-i\gamma}$ ,  $V_{td} \propto e^{-i\beta}$

# Unitarity Triangle Today



- $\epsilon_K = 2.271 \pm 0.017 \times 10^{-3}$
- $|V_{ub}/V_{cb}| = 3.7/40.$
- $\Delta m_d = 0.503 \pm 0.006 \text{ ps}^{-1}$
- $\Delta m_s > 14.4 \text{ ps}^{-1}$
- $\sin 2\beta = 0.734 \pm 0.054$

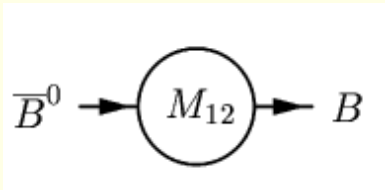
# $B^0 - \bar{B}^0$ Mixing Primer

Tagging = identify flavor of other (or same-side)  $B$

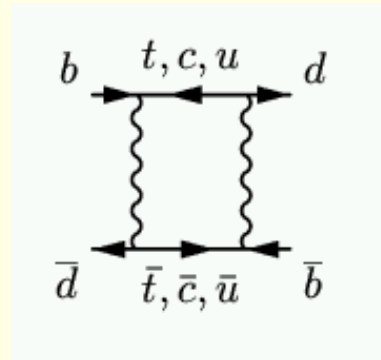
$$|B_{phys}^0(t)\rangle \propto \cos(\Delta mt/2)|B^0\rangle + i\frac{q}{p}\sin(\Delta mt/2)|\bar{B}^0\rangle$$

$$|\bar{B}_{phys}^0(t)\rangle \propto \cos(\Delta mt/2)|\bar{B}^0\rangle + i\frac{p}{q}\sin(\Delta mt/2)|B^0\rangle$$

$$q/p = -\frac{|M_{12}|}{M_{12}} = -\frac{M_{12}^*}{|M_{12}|} \quad A = \langle f|\mathcal{H}|B^0\rangle \quad \bar{A} = \langle f|\mathcal{H}|\bar{B}^0\rangle$$



Standard  
Model:



$$\propto e^{2i\beta}$$

$$\lambda = \frac{q}{p} \frac{\bar{A}}{A} : \text{independent of convention}$$

# Time-Dependence in Mixing

$$|\langle f | \mathcal{H} | B_{phys}^0(t) \rangle|^2 = |A|^2 \left[ \frac{1}{2}(1 + |\lambda|^2) + \frac{1}{2}(1 - |\lambda|^2) \cos \Delta m t - \mathcal{I}m \lambda \sin \Delta m t \right]$$

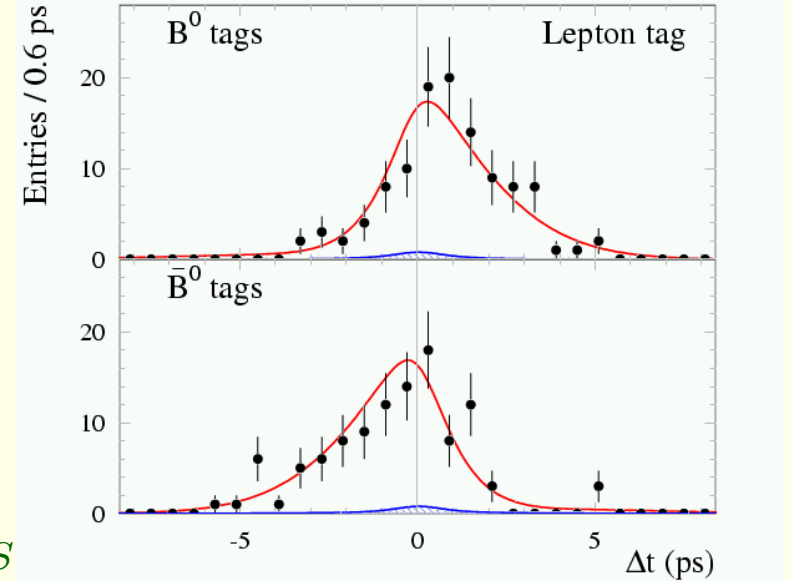
$$|\langle f | \mathcal{H} | \bar{B}_{phys}^0(t) \rangle|^2 = |A|^2 \left[ \frac{1}{2}(1 + |\lambda|^2) - \frac{1}{2}(1 - |\lambda|^2) \cos \Delta m t + \mathcal{I}m \lambda \sin \Delta m t \right]$$

When  $|f\rangle$  is a CP eigenstate and just one contributing amplitude,  $|\lambda| = 1$ :

$$|\langle f | \mathcal{H} | B_{phys}^0(t) \rangle|^2 = |A|^2 [1 - \mathcal{I}m \lambda \sin \Delta m t]$$

$$|\langle f | \mathcal{H} | \bar{B}_{phys}^0(t) \rangle|^2 = |A|^2 [1 + \mathcal{I}m \lambda \sin \Delta m t]$$

BaBar lepton-tagged  $B \rightarrow J/\psi K_S$



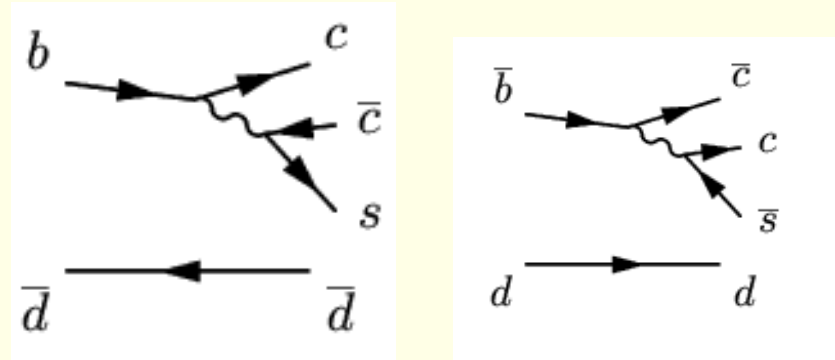
# $B \rightarrow J/\psi K_S$

1. Measure: mixing angle ( $\arg M_{12}$ )

2. Theory problems: none

3. Experimental problems: none

4. Precision in  $\sin 2\beta$



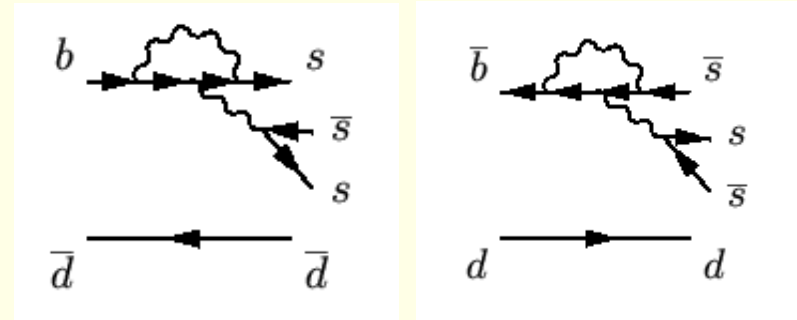
$$\lambda = \frac{q}{p} \frac{\bar{A}}{A} = \eta \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \frac{V_{cb} V_{cs}^*}{V_{cb}^* V_{cs}} = (-1) e^{-2i\beta}$$

BaBar/Belle		BTeV/LHC-b	Super B
0.1 $\text{ab}^{-1}$	0.5 $\text{ab}^{-1}$	$10^7$ s	10 $\text{ab}^{-1}$
$0.067 \oplus 0.033$	0.03	0.017	0.008

$$B \rightarrow \phi K_S$$

1. Measure: mixing angle and possible new physics penguin phase

2. Theory motivation: new physics could compete well with loop



$$\lambda = \frac{q \bar{A}}{p A} = \eta \frac{V_{tb}^* V_{td} V_{tb} V_{ts}^*}{V_{tb} V_{td}^* V_{tb}^* V_{ts}} = (-1) e^{-2i\beta}$$

3. Experimental problems: low branching ratio

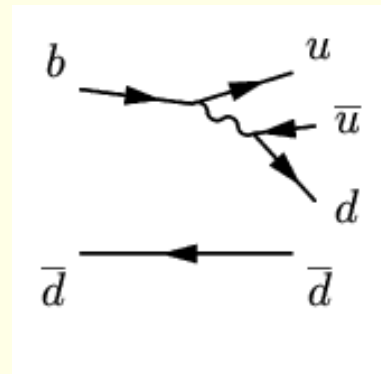
4. Precision in  $\sin 2\beta$

BaBar/Belle		BTeV/LHC-b	Super B
0.1 ab <sup>-1</sup>	0.5 ab <sup>-1</sup>	10 <sup>7</sup> s	10 ab <sup>-1</sup>
0.51 ± 0.09	0.23	0.14	0.056

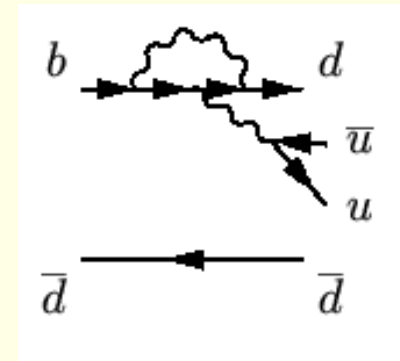
# $B \rightarrow \pi\pi$

1. Measure: mixing angle ( $\arg M_{12}$ ) plus  $2\gamma$ , i.e.  $2\pi - 2\alpha$
2. Theory concern: prominent penguin contribution
3. Experimental problems: small branching ratio for  $\pi^0\pi^0$ 
  - Penguins are  $\Delta I = 1/2$  operators, trees  $\Delta I = 3/2, 1/2$
  - Use isospin to isolate  $I = 2$  final state (no penguin contribution)

Tree



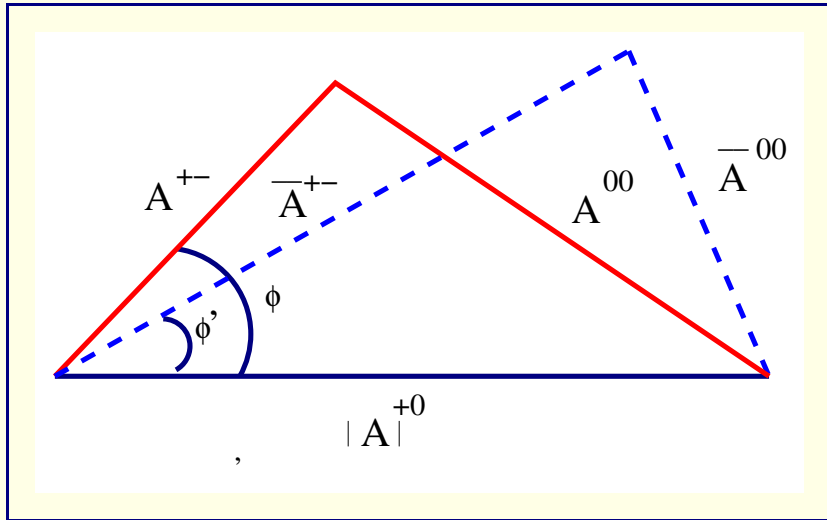
Penguin



$$\lambda_{Tree} = \eta \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \frac{V_{ub} V_{ud}^*}{V_{ub}^* V_{ud}} = e^{2i\alpha}$$

$$\lambda_{Penguin} = \eta \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \frac{V_{tb} V_{td}^*}{V_{tb}^* V_{td}} = 1$$

# Fighting Penguins in $B \rightarrow \pi\pi$



$\alpha_{eff}$  from time-dependent  $B^0, \bar{B}^0 \rightarrow \pi^+ \pi^-$

$$2\alpha = 2\alpha_{eff} + \phi - \phi'$$

(Four-fold) Ambiguity:  $\phi \rightarrow -\phi$

- Measure time-integrated  $\Gamma(B^+ \rightarrow \pi^+ \pi^0) = \Gamma(B^- \rightarrow \pi^- \pi^0)$
- Separately measure time-integrated  $\Gamma(B^0 \rightarrow \pi^0 \pi^0), \Gamma(\bar{B}^0 \rightarrow \pi^0 \pi^0)$

$$\cos \phi = \frac{\mathcal{B}(\pi^+ \pi^0) + \frac{1}{2}\mathcal{B}(\pi^+ \pi^-) - \mathcal{B}(\pi^0 \pi^0)}{\sqrt{2\mathcal{B}(\pi^+ \pi^-)\mathcal{B}(\pi^+ \pi^0)}}$$

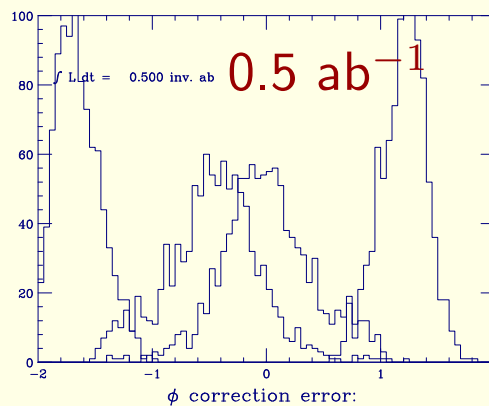
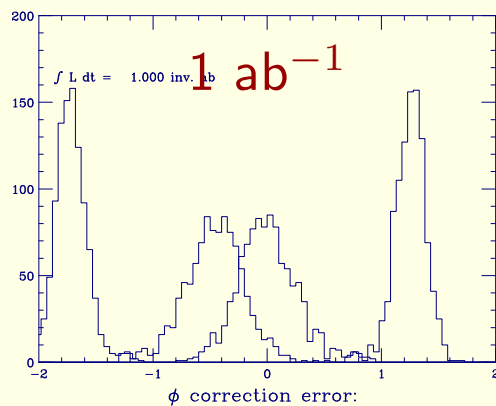
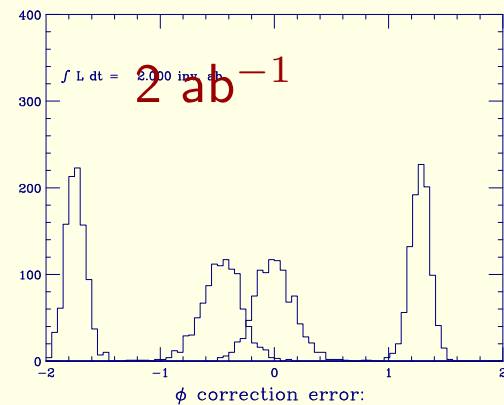
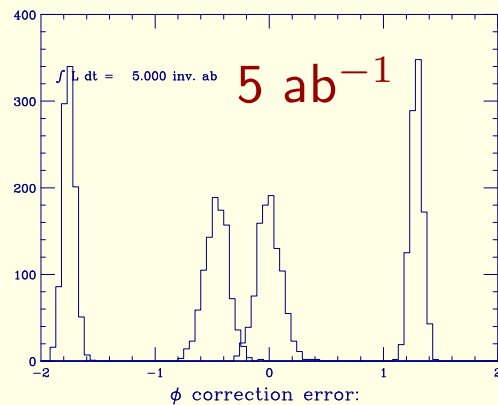
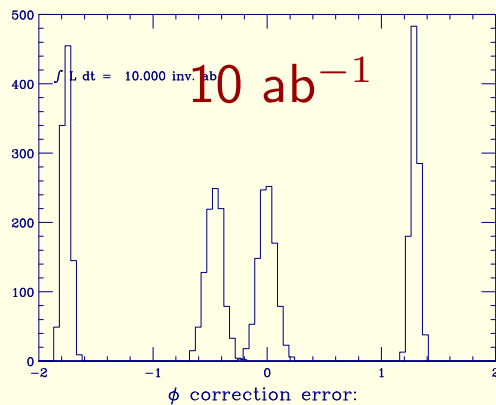
# Ambiguities Bite

- Snowmass study says  $\sigma(\alpha : \text{BaBar/Belle}) < 18^\circ$ ,  $\sigma(\alpha : \text{SuperB}) < 7^\circ$
- Toy Monte Carlo study (RNC and Roodman):

Branching ratios are in units of  $10^{-6}$ .

Background based on BaBar results

$B^\pm \rightarrow \pi^\pm \pi^0$	4.1
$B^0 \rightarrow \pi^+ \pi^-$	4.7
$\bar{B}^0 \rightarrow \pi^+ \pi^-$	4.7
$B^0 \rightarrow \pi^0 \pi^0$	2.5
$\bar{B}^0 \rightarrow \pi^0 \pi^0$	1.5



- histogram of 1000 experiments,  $-2 < \text{error in } 2\alpha_{eff} < 2$
- Precision measurement of  $\alpha$  in  $\pi\pi$  requires enormous integrated luminosity
- This seems to be a possibility only for a  $10^{36} \text{ cm}^{-2} \text{ s}^{-1} e^+e^-$  machine

# $\alpha$ from $B \rightarrow \rho\pi$

1. Measure: mixing angle  $2\beta$  plus  $2\gamma$ ,  
i.e.  $2\pi - 2\alpha$

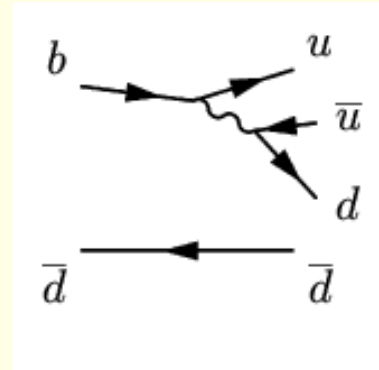
2. Theory is clean

3. Experimental problems: low  
branching ratio for  $\rho^0\pi^0$ ,  
backgrounds, most information  
comes from events with low energy  
 $\pi^0$

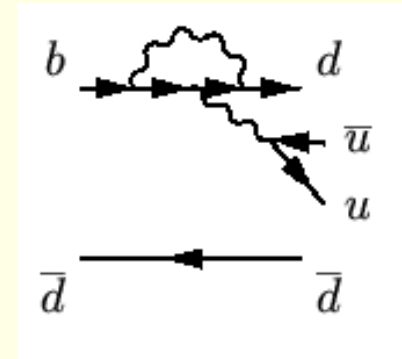
4. BTeV's calorimeter and vertex trigger provide advantages over LHC-b

5. BTeV claims resolution in  $\alpha$  of  $1.4^\circ - 4.3^\circ$  in  $2 \times 10^7$  s

Tree



Penguin



$$\lambda_{Tree} = \eta \frac{V_{tb}^* V_{td} V_{ub} V_{ud}^*}{V_{tb} V_{td}^* V_{ub}^* V_{ud}} = e^{2i\alpha}$$

$$\lambda_{Penguin} = \eta \frac{V_{tb}^* V_{td} V_{tb} V_{td}^*}{V_{tb} V_{td}^* V_{tb}^* V_{td}} = 1$$

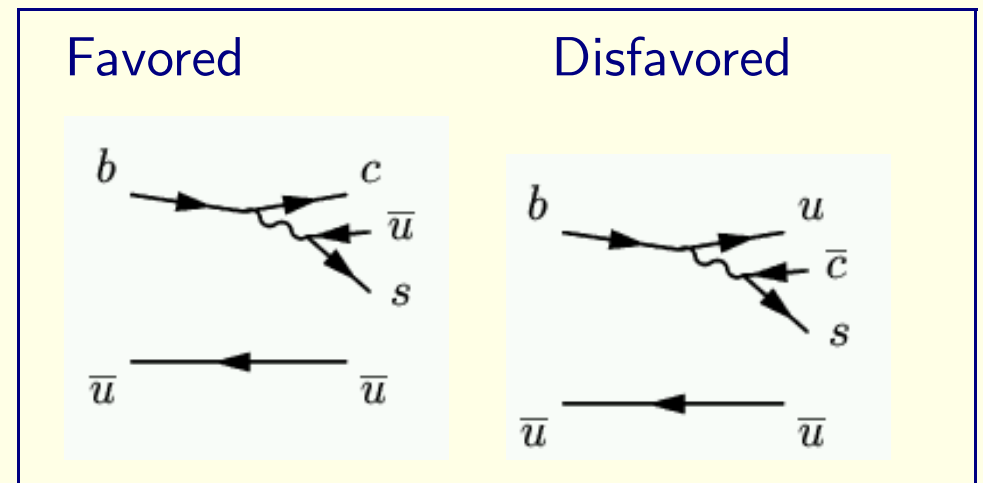
# $\gamma$ from $B \rightarrow DK$

1. Measure: interference between

$$\begin{aligned}
 B^+ &\rightarrow K^+ D^0 \text{ (disfavored)} & D^0 &\rightarrow f_i \text{ (favored)} \quad (i = 1, 2) \\
 B^+ &\rightarrow K^+ \bar{D}^0 \text{ (favored)} & \bar{D}^0 &\rightarrow f_i \text{ (disfavored)} \quad (i = 1, 2)
 \end{aligned}$$

2. Theory motivation: clean, no assumptions about final state interactions, etc.

3. Experimental problems: low branching ratios

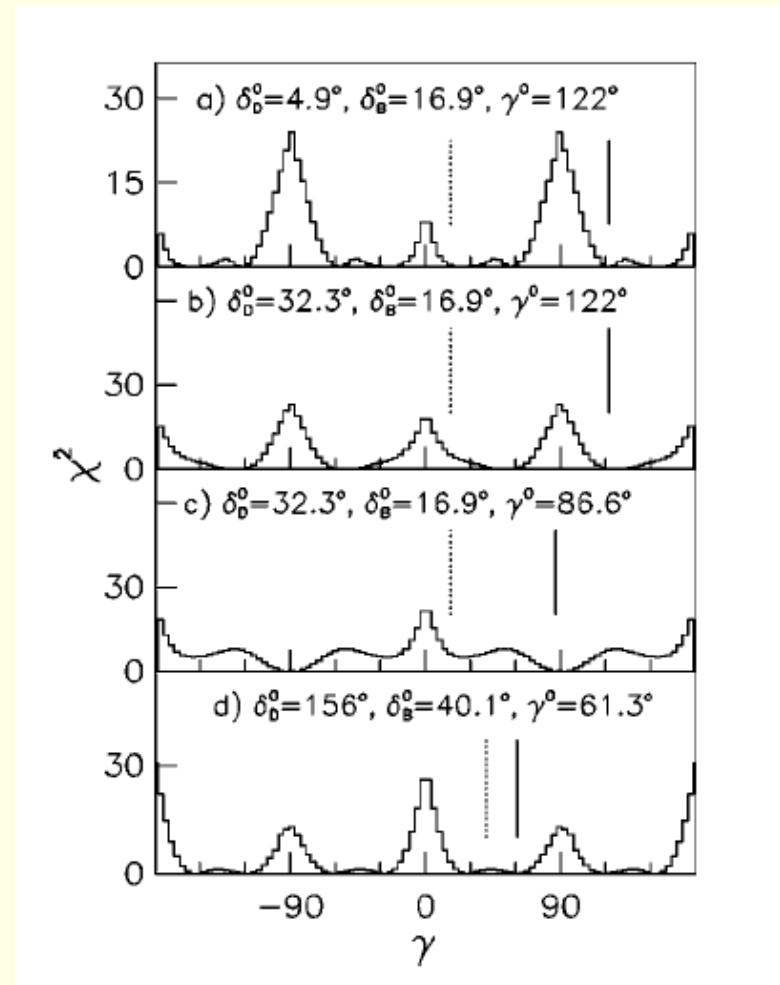


4. Measure  $B^\pm \rightarrow K^\pm f_i$ , assume  $B^+ \rightarrow K^+ \bar{D}^0$ ,  $D^0, \bar{D}^0 \rightarrow f_i$  known

5. Alternatives:  $f = CP$  eigenstate,  $f$  singly suppressed

$$\mathcal{B}(B^+ \rightarrow K^+ f_i) = \mathcal{B}(\bar{D}^0 \rightarrow f_i) \mathcal{B}(B^+ \rightarrow K^+ \bar{D}^0) + \mathcal{B}(D^0 \rightarrow f_i) \mathcal{B}(B^+ \rightarrow K^+ D^0) \\ + 2 \cos(\delta_i + \gamma) \sqrt{\mathcal{B}(\bar{D}^0 \rightarrow f_i) \mathcal{B}(B^+ \rightarrow K^+ \bar{D}^0) \mathcal{B}(D^0 \rightarrow f_i) \mathcal{B}(B^+ \rightarrow K^+ D^0)}$$

- Measure four branching ratios, learn disfavored  $\mathcal{B}(B^+ \rightarrow K^+ D^0)$ , two CP conserving phases,  $\gamma$
- Study by Abi Soffer using additional  $D^0$  decays to CP eigenstates, too
- With  $600 \text{ fb}^{-1}$ , hard to exclude large regions of  $\gamma$
- With  $10 \text{ ab}^{-1}$ , extrapolate at SuperB  $\gamma$  to  $1^\circ - 2.5^\circ$



- Exclusive approach to  $V_{cb}$ :  $B \rightarrow D\ell\nu$ ,  $B \rightarrow^* \ell\nu$ 
  - Measure  $|V_{cb}| \times \text{form factor}$ , known to  $\approx 4\%$
- Inclusive approach to  $V_{cb}$ 
  - Theory under good control: 2%
- Inclusive approach to  $V_{ub}$ 
  - Make cut in  $E_\ell$  to remove bkgd from  $b \rightarrow c\ell\nu$
  - Now theory has uncertainties
  - Could cut on  $m_{hadronic} < m_D$
  - Theory still not under control
  - Better to require  $q^2 = m_{\ell\nu}^2$  large: fully reconstruct other  $B$
  - May reduce theory uncertainty for  $|V_{ub}|$  to 5%
- : Exclusive approach to  $V_{ub}$ : lattice calculation of form factors

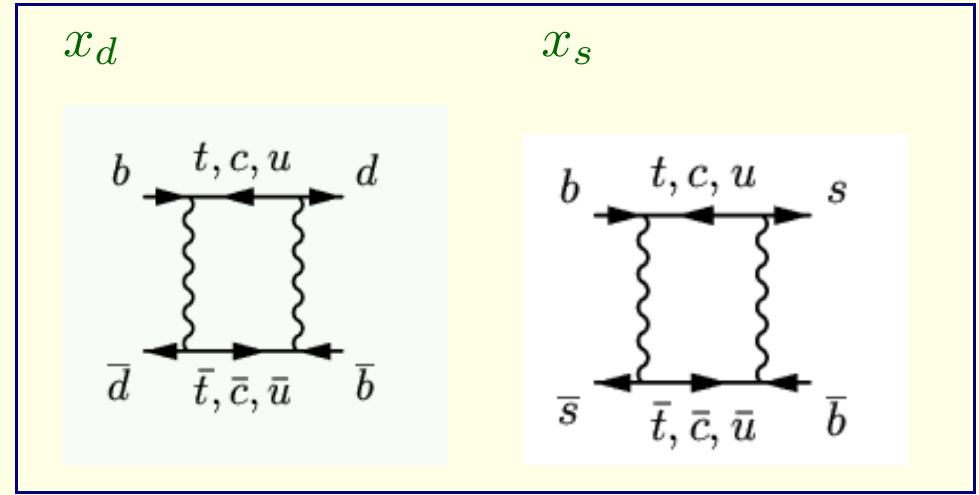
# $B_s$ oscillations: $x_s$

1. Measure: mixing in  $B_s - \bar{B}_s$  system

2. Theory issue:

$$x_s/x_d = \frac{m_{B_s} \eta_{B_s} B_{B_s} f_{B_s}^2}{m_{B_d} \eta_{B_d} B_{B_d} f_{B_d}^2} |V_{ts}/V_{td}|^2$$

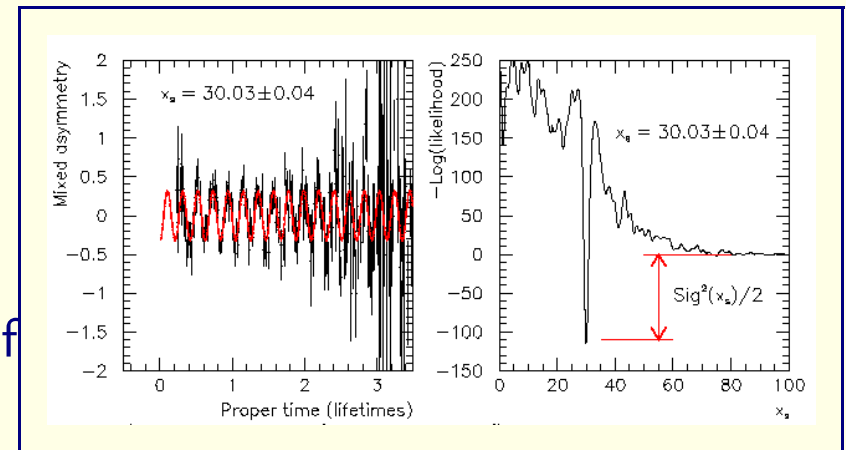
introduces 10% uncertainty in  $|V_{td}/V_{td}|$



3. Experimental problems: need  $B_s$ !

4. CDF should measure  $x_s$  with good precision

5. Lattice calculations needed to get full benefit of BTeV measurement

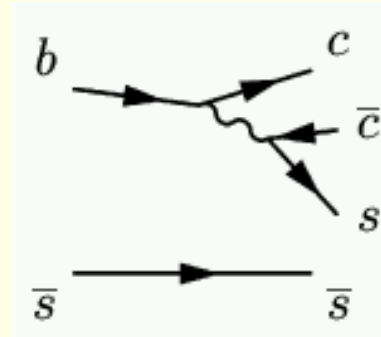


$$B_s \rightarrow J/\psi \phi, J/\psi \eta'$$

1. Measure: analog of  $B \rightarrow J/\psi K_S$   
No 1st to 3rd, so no asymmetry to lowest order in  $\lambda_{CKM}$

$$\chi \approx \lambda_{CKM}^2 \eta$$

2. Theory motivation: new physics with phase of  $B_d - \bar{B}_d$  mixing would show up



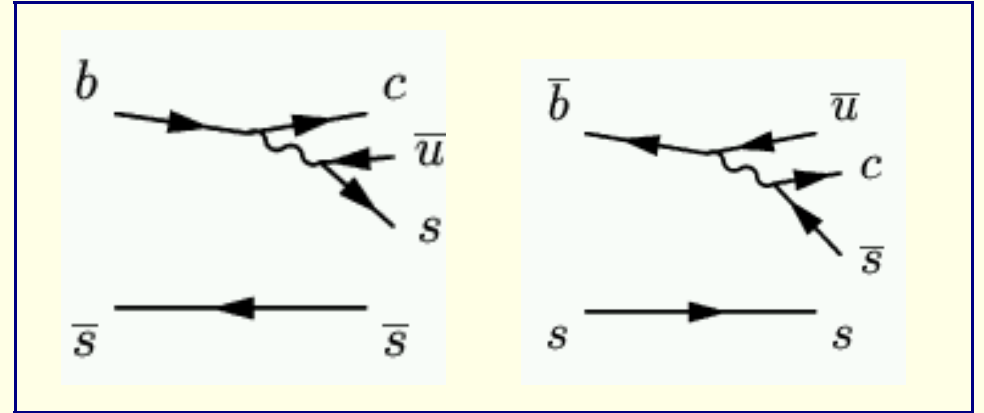
$$\lambda = \frac{q}{p} \frac{\bar{A}}{A} = \eta \frac{V_{tb}^* V_{ts}}{V_{tb} V_{ts}^*} \frac{V_{cb} V_{cs}^*}{V_{cb}^* V_{us}} = 1$$

3. Experimental problems: requires  $B_s$ , good spatial resolution

4. BTeV reach in  $\sin 2\chi : \pm 0.024$

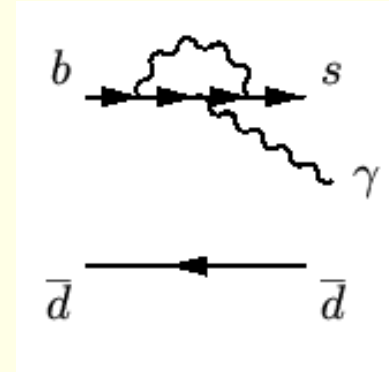
# Measuring $\gamma$ in $B_s \rightarrow D_s^\pm K^\mp$

- Both  $B_s$  and  $\bar{B}_s$  decay to  $D_s^\pm K^\mp$  at same order
- Unlike  $B_d$  analog (amplitudes dissimilar sizes)
- True oscillation experiment:  $B^0$  and  $\bar{B}^0$  decay to same state
- BTeV uncertainty estimated at  $13^\circ$
- Much harder at  $e^+e^-$  collider



$$b \rightarrow s \gamma$$

1. Experimental issue: get rid of enormous  $\gamma$  bkgd from  $\pi^0$ ,  $\eta$ , etc.

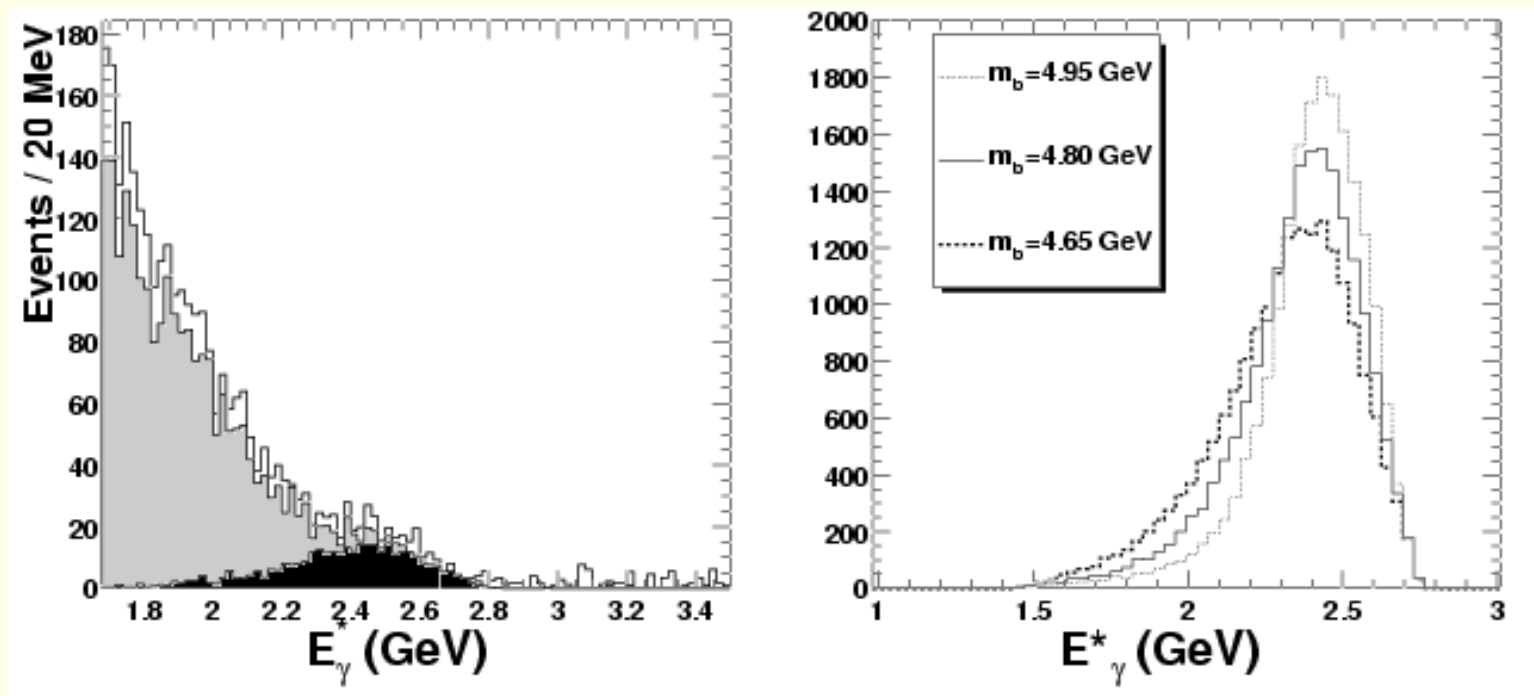


2. Theory issue: lowest order is already one loop so new physics should be prominent

3. Experimental problems: backgrounds, need model to get full spectrum

- To reduce background, require  $E_\gamma^* > E_{min}$
- Require lepton from other  $B$  to remove continuum; MC to remove  $B^0 \bar{B}^0$  bkgd
- Need theory for spectrum, not just total rate
- Theoretical prediction for spectrum above 2.2 GeV uncertain by about 15%

# $b \rightarrow s \gamma$ Backgrounds, Extrapolation



Uncertainty in  $m_c$  limits precision of extrapolating below 2.1 GeV. BaBar ICHEP presentation, based on Kagan and Neubert.

# $b \rightarrow s \gamma$ Theory Issues

- At high energies, ignore QCD [asymptotic freedom]
- QCD corrections plus QED generate effective low energy interactions

$$\mathcal{O}_2 = \bar{s}_L \gamma_\mu c_L \bar{c}_L \gamma^\mu b_L \text{ [ordinary weak interaction]}$$

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b \bar{s}_L \sigma^{\mu\nu} b_R F_{\mu\nu}$$

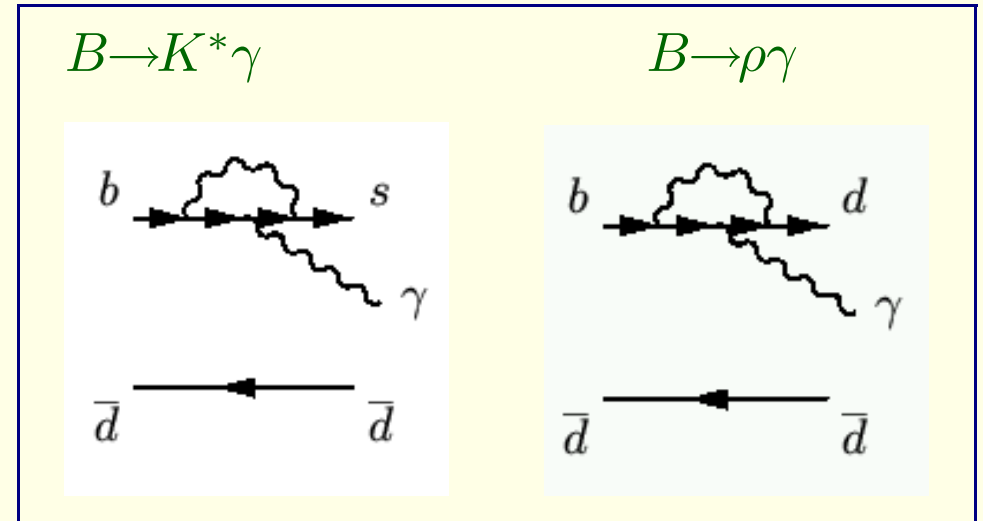
$$\mathcal{O}_8 = \frac{g_s}{16\pi^2} m_b \bar{s}_L \frac{1}{2} \lambda^a \sigma^{\mu\nu} b_R G_{\mu\nu}^a$$

$$\mathcal{H} \propto \sum_j C_j(\mu) \mathcal{O}(\mu)_j$$

$$C_j(m_b) = \sum_k (\text{evolution coef.})_{jk} C_k(m_W)$$

$$B \rightarrow K^* \gamma / B \rightarrow \rho \gamma$$

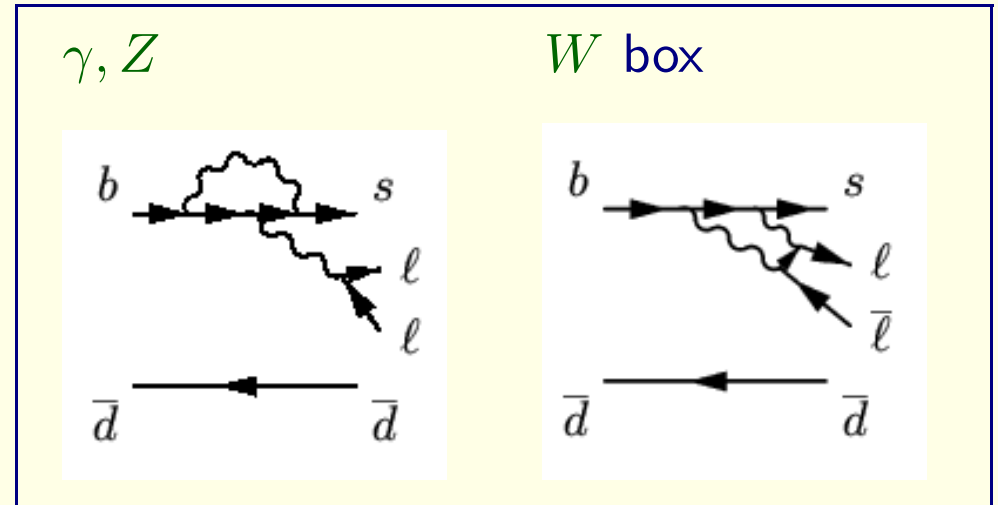
1. Measure exclusive decays
2. Theory issue: non-perturbative matrix element
3. Ratio gives  $|V_{ts}/V_{td}|^2$ , but with model dependence
4. Experimental: clean for  $K^*$ , small rate for  $\rho$



$$b \rightarrow s \ell \bar{\ell}$$

1. Measure exclusive decays and sum, excluding in  $J/\psi$  etc.

2. Theory issue: probes  $\gamma, Z$  and  $W$  box diagrams



3. Experimental: clean for  $K^* \ell \bar{\ell}$

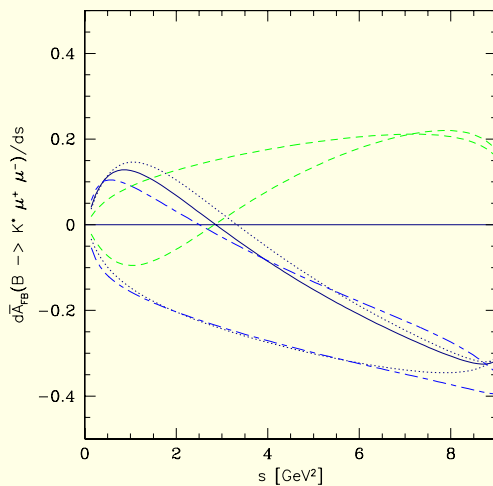
New Operators:

$$\mathcal{O}_9 = \frac{e}{16\pi^2} \bar{s}_L \gamma_\mu b_L \bar{\ell} \gamma^\mu \ell$$

$$\mathcal{O}_{10} = \frac{e}{16\pi^2} \bar{s}_L \gamma_\mu b_L \bar{\ell} \gamma^\mu \gamma_5 \ell$$

# $b \rightarrow s \ell \bar{\ell}$ Forward-Backward Asymmetry

- Comes from interference between axial ( $\mathcal{O}_{10}$ ) and vector ( $\mathcal{O}_{7,9}$ )
- Need to understand various form factors evaluated at  $s = m_{\ell\bar{\ell}}^2$
- New Physics can enter through  $\mathcal{C}_{7,9,10}$



Forward-Backward Asymmetry in  $B \rightarrow K^* \mu^+ \mu^-$  for SM and some SUSY models,  
Ali, et al. PRD 61, 074024  
BTeV, SuperB will have 1000's of events

$$K^+ \rightarrow \pi^+ \nu \bar{\nu}$$

1. Measure one charged particle!

2. Theory issue:

$$\mathcal{A} \propto V_{td}, |\mathcal{A}|^2 \propto (1 - \rho)^2 + \eta^2$$

with charm contribution

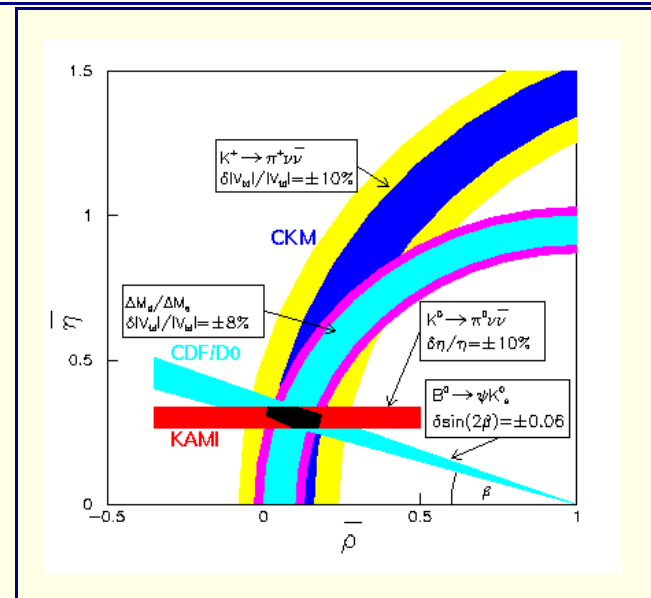
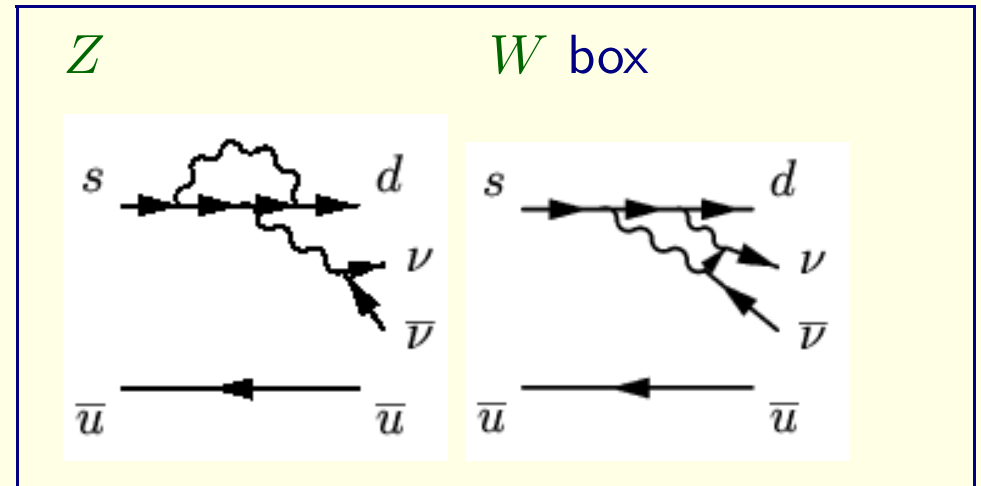
$$\rightarrow |\mathcal{A}|^2 \propto (1.42 - \rho)^2 + \eta^2$$

3. Experimental: very low branching ratio

$$0.77 \pm 0.21 \times 10^{-10} \text{ (th)},$$

$$1.5^{+3.4}_{-1.2} \times 10^{-10} \text{ (exp)}$$

4. CKM aims for 100 events



$$K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$$

1. Measure two photons !

2. Theory issue: cleanly measures  $\eta$

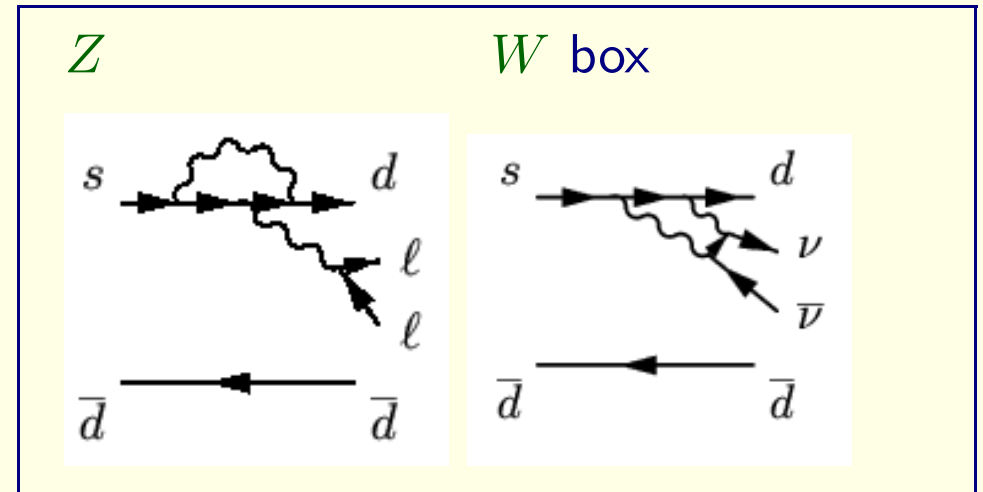
$$|K_L\rangle = [|K^0\rangle - |\bar{K}^0\rangle]$$

$$\mathcal{A} \propto V_{td} - V_{td}^* = \eta$$

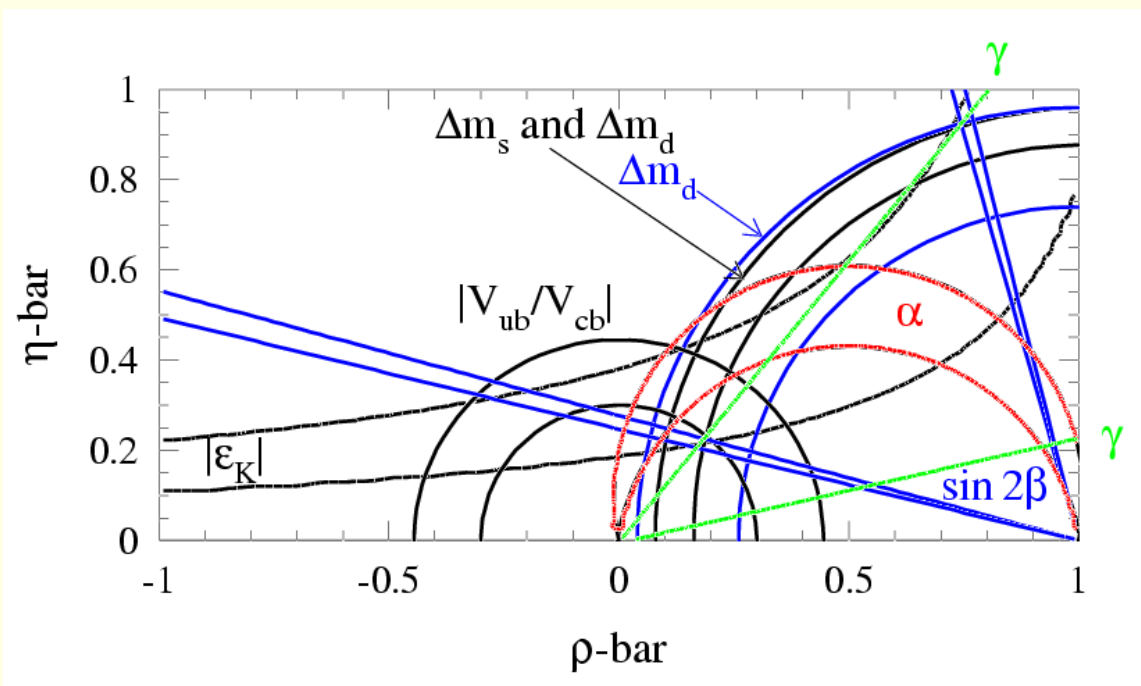
3. Experimental: very tough!!

4. KOPIO - part of RSVP - bunched beam  $\rightarrow$  TOF  $\rightarrow K_L$  momentum

5. Goal is 10% measurement of  $\eta$

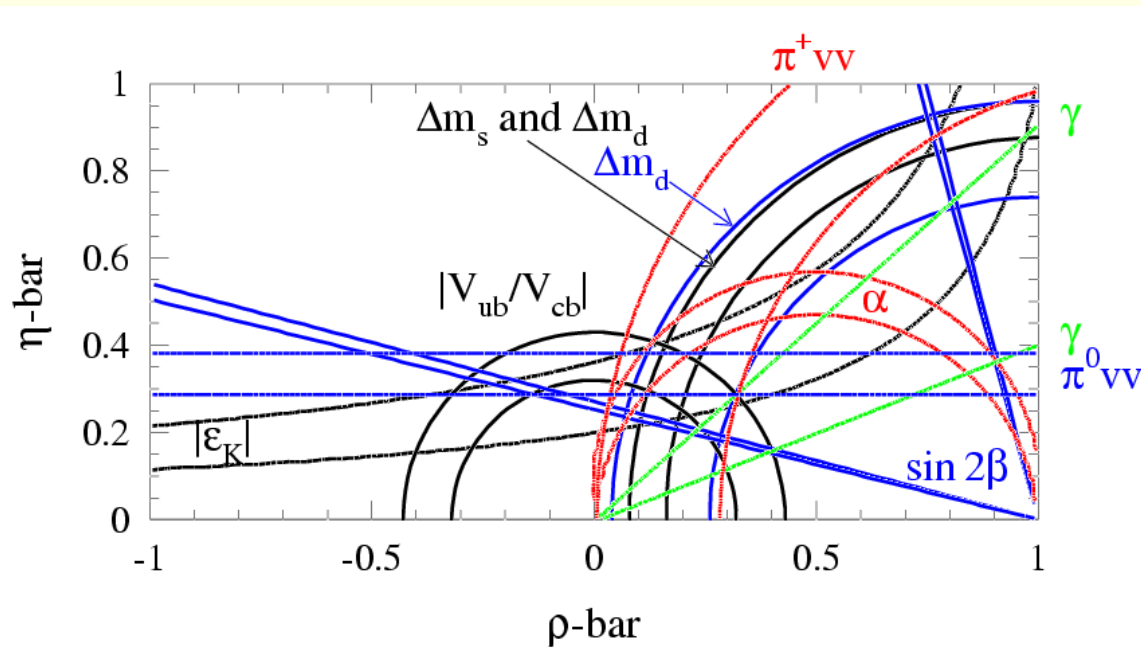


# Projection by CKMFitter Team



- $\Delta m_s : \pm 0.2\%$
- $\sin 2\beta : \pm 0.01 \pm 0.01$
- $\alpha : \pm 5^\circ$
- $\gamma : \pm 10^\circ$
- $|V_{ub}| \pm 10\%$

# More Ambition Projection by CKMFitter Team



- $\Delta m_s : \pm 0.2\%$
- $\sin 2\beta : \pm 0.007$
- $\alpha : \pm 2^\circ$
- $\gamma : \pm 6^\circ$
- $|V_{ub}| \pm 10\%$
- $\mathcal{B}(K_L \rightarrow \pi^0 \nu \nu) : \pm 7\%$
- $\mathcal{B}(K^+ \rightarrow \pi^+ \nu \nu) : \pm 5\%$

# Spirit of Next Generation Flavor Physics

- Standard Model likely to have been verified to basic level:
  - Success of SM in  $\sin 2\beta$  impressive
  - Had been likely target for deviation
- Only deviations that are truly convincing are likely to be interesting
  - 2  $\sigma$ : 50 theory papers
  - 3  $\sigma$ : 250 theory papers
  - 5  $\sigma$ : strong sign of effect

# Beyond the Standard Model: Now and Then

- Now

- Pick model e.g. Minimal Supersymmetric Standard Model
- Restrict it to reduce free parameters
- Constrain parameters so no egregious violations of current data
  - \* EDM
  - \*  $\epsilon, \epsilon'/\epsilon,$
  - \*  $\Delta m_d, \sin 2\beta, b \rightarrow s\gamma$
- Predict other observables in  $B$  system

- Then

- Pick model consistent with LHC discoveries and exclusions
- Vary parameters, look for observable effects
- Use flavor physics results to constrain models

# Summary

- Many channels for  $K, B_d, B_s$  decays that have great interest
- Three worthy paths
  - Test QCD-improved electroweak theory
  - Validate Standard Model
  - Look beyond Standard Model
- Some channels that are theoretical and experimentally clean
  - $B \rightarrow J/\psi K_S, B \rightarrow \phi K_S, B_s \rightarrow J/\psi \phi(\eta'), B \rightarrow DK, B_s \rightarrow D_s K, K \rightarrow \pi \nu \bar{\nu}$
- Some require advances in QCD corrections/lattice gauge calculations
- By uncovering new quanta, LHC will raise the bar for flavor physics